15 January Draft

An XMM-Newton Survey of SDSS Stripe 82

Gordon T. Richards,[1] S. Anderson, F. Bauer, W.N. Brandt, R. Brunner, K. Covey, M. Elvis, X. Fan, S. Hawley, S. Jester, M. Lacy, T. McKay, A. Myers, K. Romer, D. Spergel, D. Schneider, M. Strauss, N. Zakamska

ABSTRACT

We briefly describe the synergy between the deep, multi-epoch, multi-wavelength SDSS Stripe 82 data and a potential co-located *XMM-Newton* X-ray survey to 1–5$\times10^{-15}$ ergs/s/cm^2. The two surveys have well-matched flux limits that would enable key AGN science.

1. The Sloan Digital Sky Survey Southern Equatorial Stripe

The SDSS has demonstrated its power as the premier wide-area, moderate-depth optical survey, covering roughly one quarter of the sky in the Northern Galactic cap to a depth of $g \sim 22.5$. In addition, during the Fall months, the SDSS imaging camera repeatedly scans a 120° long by 2.5° wide stripe along the Celestial Equator in the Southern Galactic Cap ("Stripe 82"). To date, over 40 epochs of data spanning over 8 years exist along this stripe. Co-adding these data brings the limiting magnitude to $g \sim 24.5$, while the individual scans give detailed variability information for stars and AGN.

The deep 5-band SDSS imaging is complemented by *GALEX* UV coverage to $m_{UV} =$ 20.5–23, VLA FIRST survey radio coverage at 20 cm to 1 mJy, and UKIDSS near-IR coverage to $K_{AB} = 20.1$ (data now public). Furthermore, the VISTA Hemisphere Survey will image Stripe 82 to $J_{AB} = 22.1$. Our own group has recently obtained additional A-array VLA data (50 deg^2) tripling the depth at 20 cm and we are currently obtaining JK data with NEWFIRM on the 4m at KPNO. Also, the Atacama Cosmology Telescope has started to observe this field to ~ 1 mJy at mm wavelengths. Extensive spectroscopic followup has been conducted in Stripe 82, using both the SDSS spectrographs (see Adelman-McCarthy et al. 2006) and the 2dF and AAOmega spectrographs (e.g., Croom et al. 2004). The existing spectral density is roughly 500 deg^{-2} (the densest coverage of any field this size) and the WiggleZ survey (Glazebrook et al. 2007) is targeting $0.5 < z < 1$ galaxies in this area. Thus, the combination of multi-epoch and multi-wavelength coverage in the proposed field is unique (Fig. 1).

[1]Department of Physics, Drexel University, 3141 Chestnut Street, Philadelphia, PA 19104.

2. AGN Science

AGN Census: AGN surveys are inherently biased, incomplete, and contaminated. As such, in order to obtain a complete AGN census, it is important to conduct multiwavelength surveys. An *XMM-Newton* survey will complement the existing multi-epoch optical data by finding obscured AGNs and other AGNs with weak optical signatures. *Spitzer* data, whether in Cycle 5 or as part of the warm mission, will fill in the gaps due to highly Compton-thick and X-ray weak AGNs. While existing X-ray surveys have provided the depth to recover thousands of AGNs per square degree, the existing fields are too small to recover large numbers of luminous and high-redshift AGNs. An *XMM-Newton* survey to 1–5$\times 10^{-15}$ ergs/s/cm^2 (requiring a few tens of ks) nicely complements the existing SDSS data set as an $i = 22$ type 1 quasar at $z = 2$ with a normal optical to X-ray flux ratio ($\alpha_{ox} = -1.5$) corresponds to an XMM flux of $\sim 6 \times 10^{-15}$ ergs/s/cm^2; see Figure 2. For an X-ray weak quasar ($\alpha_{ox} = -1.8$), the value is $\sim 1 \times 10^{-15}$ ergs/s/cm^2.

Models of AGN demographics predict tens of thousands of obscured AGNs at the proposed depth/area (Treister et al. 2004, Ballantyne et al. 2006), whereas the number that are luminous enough to have been spectroscopically confirmed (e.g., Zakamska et al. 2003; Reyes et al. 2008) is considerably smaller. The resulting combined (hard X-ray through IR/radio) Stripe 82 catalog will aid in investigating 1) the population of obscured quasars as a function of luminosity and redshift, and 2) the shape of the luminosity function and quasar clustering and their relationship to AGN "feedback".

Variability Selection: Our deep optical data from SDSS Stripe 82 complements X-ray and IR selection with variability information. On timescales of years, essentially all luminous, type 1 AGNs are variable at a level that is measurable with the SDSS Stripe 82 data set (to the single epoch SDSS flux limit of $g \sim 22$); see Figure 3. *There are no other comparable data sets to date* in terms of areal and time-domain coverage. A combination of X-ray, mid-IR, and variability selection should identify essentially *all* type 1 quasars in the proposed area. The primary source of contamination for variability selection is RR Lyrae stars, which can be removed with additional IR and/or X-ray information. While both Pan-STARRS (beginning now) and LSST (beginning in 2015) will also provide similar variability data, *it will be 8 years from their start dates before a comparable data set has been compiled*, and Pan-STARRS will lack u-band data (crucial for photometric redshifts and helpful for rejection of variable stars). Furthermore, coupling with the deep SDSS optical data allows for robust star-galaxy separation to $g \sim 22.5$ (vs. $g \sim 21$ for the single epoch SDSS scans).

Probing AGN Feedback: The tight correlations between galaxy spheroid properties and the supermassive black holes they host (e.g., Ferrarese & Merritt 2000; Gebhardt et al. 2000) suggest that active nuclei play an important role in the formation of spheroids. As recent galaxy evolution models invoke "AGN feedback" (e.g., Hopkins et al. 2006), measurements of AGN properties, in particular their luminosity function and clustering, provide important probes of galaxy evolution. This work requires both depth (to probe the faint end of the luminosity function and the luminosity dependence of clustering) and area (to find rare objects [high-z and luminous sources]).

Despite decades of quasar surveys, the range of redshift, luminosity, and area coverage is insufficient to fully test feedback models using the shape and evolution of the QLF; see Figure 4. Existing X-ray and IR surveys do not cover enough area (at an appropriate depth) and optical surveys miss obscured AGNs (Hopkins et al. 2007). Deep, wide-area IR (e.g., Brown et al. 2006) and X-ray surveys continue to be in demand to fill in the gap. In addition, using the SDSS 5-band photometry alone, it is possible to determine photometric redshifts for quasars to an accuracy of $\Delta z = 0.3$ about 80% of the time. Additional multiwavelength data allows further improvements.

The most statistically precise way of measuring quasar clustering is to compare the quasar-galaxy cross-correlation amplitude to that of the galaxy-galaxy autocorrelation (e.g., Coil et al. 2007). A 100 deg^2 survey will allow meaningful clustering estimates in several bins of redshift and luminosity. X-ray observations of this area will be particularly important as the luminosity dependence of quasar clustering is a sensitive probe, independent of the QLF, of the differences between the two standard models of AGN/galaxy formation (lightbulb vs. evolutionary; e.g., Lidz et al. 2006). A combined Stripe 82-XMM data set will be particularly powerful, allowing clustering to be probed over a broad dynamic range in luminosity and redshift (as in, e.g., Myers et al. 2006, 2007; Shen et al. 2007). The X-ray-IR-optical nature of the coverage is key to (1) increasing the dynamic range of quasar luminosities towards the Seyfert regime; (2) minimizing quasar and galaxy photometric redshift errors, and (3) extending the sample to higher redshift.

3. Summary of SDSS Stripe 82 Field Properties

• 40+ epochs of SDSS *ugriz* imaging data spanning 8 years; co-added depth of $g \sim 24.5$
• VLA 20 cm data coverage to 0.3 mJy (from FIRST and our new A-array obs.)
• *GALEX* UV to m_{UV} ∼20.5–23
• UKIDSS near-IR $YJHK$ coverage to $K = 20.1$; proposed VISTA coverage to $J = 22.1$
• NEWFIRM near-IR YK coverage to $K = 22$ underway
• Pan-STARRS, PS1 (Chambers et al. 2005) coverage at least 0.5 mag deeper than SDSS co-added data in *griz* and 1 mag deeper than UKIDSS in Y
• Millimeter (1.1–2.0mm) coverage to ~ 1 mJy with ACT
• Over 500 optical spectra per square degree (over 10,000 spectra in the proposed area)
• 98% of area has $E(B-V) < 0.1$, 73% < 0.05
• Equatorial location, accessible to telescopes in both hemispheres
• Ability to perform 9-band ($ugrizYJHK$) photometric redshifts
• Ability to extend to a larger contiguous area with existing ancillary data
• Proposed *Spitzer* observations to give $\sim 5\mu$Jy depth at 3.6μm

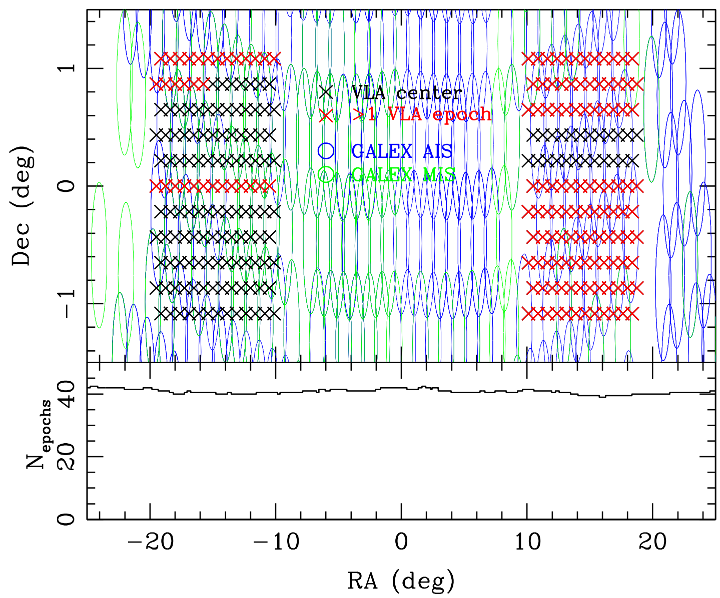

Fig. 1.— *Top:* Proposed areal coverage as outlined by existing deep (3x FIRST) VLA coverage (black x's). Some VLA fields have even deeper coverage from additional time awarded from dynamic scheduling (red x's). GALEX AIS and MIS coverage are given by blue and green circles. *Bottom:* Number of epochs of SDSS data along Stripe 82.

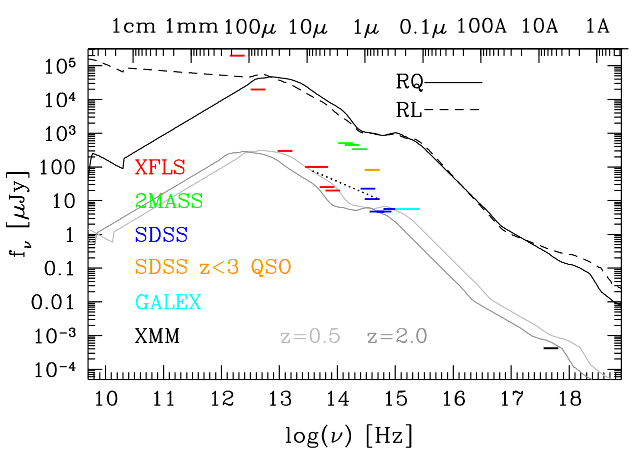

Fig. 2.— Relative multiwavelength flux density limits for type 1 quasars. The top curves represent $z = 0$ radio-loud and radio-quiet quasars with $i = 16.4$ (1mJy). The bottom curves represent $z = 0.5$ and $z = 2$ radio-quiet quasars with $i = 22$ (5.5μJy), which closely matches the proposed XMM-wide flux limit of 1–5$\times10^{-15}$ergs/s/cm^2. Note that a flux density of 1.0$\times10^{-15}$ergs/s/cm^2/keV corresponds to 1nJy at 1×10^{17}Hz (0.4keV).

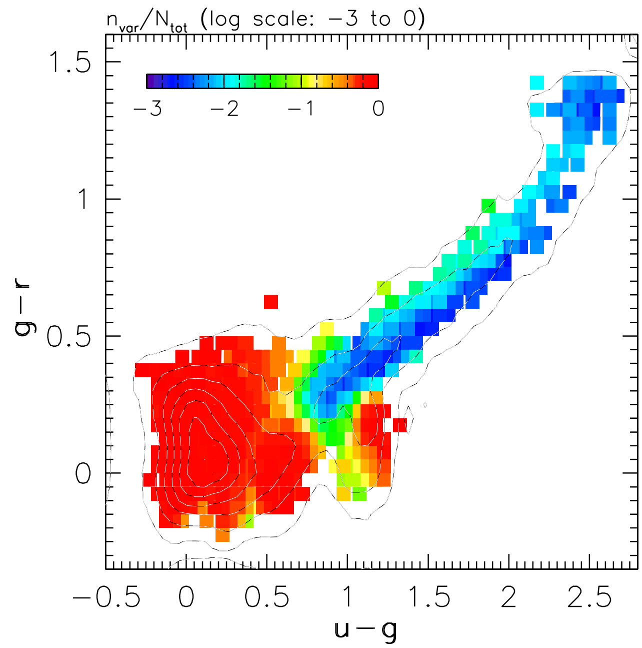

Fig. 3.— Demonstration of variability selection of AGNs. Quasars are shown by the large red blob. RR Lyrae stars are the smaller red blob. Both are clearly distinguished from normal stars. Note the importance of the u filter (lacking in Pan-STARRS) for distinguishing the two variable populations.

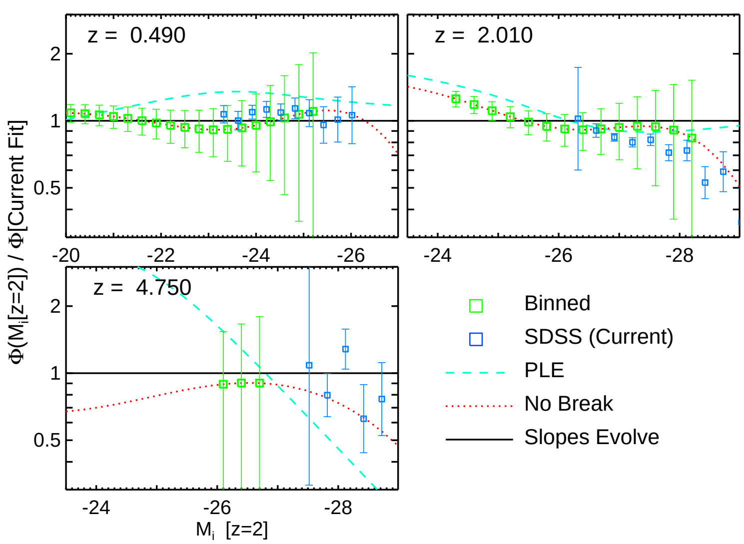

Fig. 4.— Predicted QLF in 3 redshift bins for a 100 deg^2 AGN survey. Blue points are the SDSS-DR3 QLF. Green are the predicted QLF. Three model curves are shown; the Stripe 82 data will help resolve the issue of which models best fits the redshift evolution of the faint-end slope and whether the bright end slope is truly flatter at high-z than low-z. (Courtesy P. Hopkins)